Experimental Investigation on Performance Characteristics of Four Stroke Diesel Engine using Oil Derived from Waste Tyre

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***Abstract*:- Using a liquid fuel derived from waste tyres in Diesel engines was evaluated in this paper. The liquid fuel was obtained by thermal cracking process carried out at moderate temperatures (300–500°C). Fuel properties of the pyrolysis oil were analysed density, viscosity, calorific value and flash point comparable to those of a Diesel fuel. An engine investigation was carried out on a single-cylinder four stroke Diesel engine using tyre pyrolysis oil (TPO) Diesel blends TPO10, TPO20 and TPO30 for performance characteristics and the results were compared with those of the diesel. Engine performance, evaluated at different engine speed and loads, showed that the use of TPO20 didn't had much difference in terms of torque, power and specific fuel consumption in respect to those obtained using the diesel.**

I. INTRODUCTION

Tyre recycling has become a necessity because of the huge piles of tyres that represent a threat to the environment. The used tyres represent a source of energy and valuable chemical products.[1] The disposal of used automotive tyres is an increasing economic and environmental problem for most of the developed countries. It is estimated that 2.5 million tons per year are generated in the European Union, 2.5 million tons in North America and around 1 million in Japan. Tyre is made of rubber materials (poly butadiene, styrene–butadiene rubber and poly isoprene or natural rubber), carbon black and some fibrous materials. It has high volatile and fixed carbon contents with heating value greater than most of the coals. These characteristics make rubber from old tyre a good raw material for thermochemical processes. On the other hand, scrap tyre is bulky and is not a biodegradable residue and, therefore, it is not possible to achieve its degradation in landfills. As a consequence, open dumping of scrap tyre not only occupies a large space, presents an eyesore, cause potential health and environmental hazards but also illustrates wastage of valuable energy resource.[2] The negative environmental impacts caused by disposal of waste automotive tyres in landfills or by incineration can be reduced by recovery of constituent chemicals and energy content by a number of available technologies. The conventional methods for energy recovery are based on simple combustion in cement kilns. Also, tyre powder is often used as compounding for low value rubber goods. However, all these combined applications do not solve the waste tyre-stockpiling problem and does not result in adequate profitability. Tyre pyrolysis at present is an interesting and challenging area of research. [3] Pyrolysis is the process of thermally degrading a substance into smaller, less complex molecules. Pyrolysis produces three principal products: such as pyrolytic oil, gas and char. The quality and quantity of these products depend upon the reactor temperature and design. In the Pyrolysis process, larger hydrocarbon chains break down at certain temperatures in the absence of oxygen that gives end products usually containing solids, liquids and gases. If the temperature is maintained at 550 ºC, the main product is a liquid, which could be a mixture of various hydrocarbons depending on the initial composition of the waste material. At temperatures above 700 ºC, the gas becomes the primary product due to further cracking of liquids. The gas is basically composed of CH4, with C2H6, C2H4, C2H2, and other gaseous hydrocarbons however in lesser quantities. The quality and quantity of these products depend upon the reactor temperature and design. [4] Tyre pyrolysis oil (TPO) is mainly constituted by aromatics and aliphatic hydrocarbons, with some properties, such as calorific value and density, similar to those of Diesel fuel, while others, as viscosity, can vary in accordance to the specific pyrolysis process adopted. However, its utilisation in energy conversion devices, such as internal combustion engines, needs some preventative measures that depend on the specific application. In the case of Diesel engines, TPO, because of its low cetane number, must be mixed with Diesel fuel or complemented by a cetane improver, for example diethyl ether. Moreover, the high sulphur content in TPO can require appropriate desulphurization methods to meet stringent exhaust SO_2 limits. TPO has largely variable chemical–physical characteristics and can be employed as fuel in a wide range of Diesel engines. Of course, big engines (for instance, large stationary engines and medium/ low speed engines for marine propulsion) are the most suitable to be fuelled with TPO since they are less fuel-quality demanding and are submitted to less stringent emission regulations. However, it is worth considering TPO employ in small engines, e.g. for small electric generators or for agricultural applications, since it may well lead to a widespread energetic utilisation of scrap tyres.[5] In the present study, TPO-Diesel blends were used as a fuel in a single cylinder four stroke diesel engine. The performance, emission and combustion characteristics of the engine were analysed and compared with diesel fuel operation.

II. MATERIALS AND METHODS

Initially an automobile tyre was cut into small pieces and the bead, steel wires and fabrics were removed. Thick rubber at the periphery of the tyre was alone made into small chips. The tyre chips were washed, dried and fed in to a mild steel pyrolysis reactor unit. The reactor unit used was a fully insulated cylindrical chamber of inner diameter 110 mm and outer diameter 115 mm and height 300 mm. Vacuum was created in the pyrolysis reactor and then externally heated by means of 1.5 kW heaters.

The process was carried out between 450°C and 650°C in the reactor for 90 minutes. The products of pyrolysis in the form of vapour were sent to a water cooled condenser and the condensed liquid was collected as a fuel. The non-condensable gases were let out into atmosphere. The TPO collected was crude in nature. For an output of 1 kg of TPO about 2.09 kg of waste tyre is required. The product yields from the process are tyre Pyrolysis oil (50%), Pyro gas (40%) and char (10%). The heat energy required to convert the waste tyre into the products was around 7.8 MJ/kg. TPO was filtered by fabric filter and again filtered by micron filter to remove impurities.

Initially crude TPO was heated upto 100°C, in a cylindrical vessel for a particular period to remove the moisture, before subjecting it to any further chemical treatment. The moisture free crude TPO contains impurities, carbon particles and sulphur particle. A known volume of concentric hydro sulphuric acid (6%- 8%) was mixed with crude TPO and stirred well. The mixture was kept for about 20 hours. After 20 hours, the mixture was found to be in two layers. The top layer was a thin mixture and lower one was thick was sludge. The top layer was taken for vacuum distillation and the sludge was removed and disposed off.

Vacuum distillation process was carried out to separate the lighter and heavier fraction of hydrocarbon oil. A known sample of chemically treated crude TPO was taken for vacuum distillation process. The sample was externally heated in a closed chamber. The vapour leaving the chamber was condensed in a water condenser and the DTPO was collected separately. Non condensable volatile vapour was left to the atmosphere. The distillation was carried out between 150°C and 200°C. 80% of TPO was distilled in the distillation whereas 5% of TPO was left out as pyro gas and 15% was found as sludge.

III. PROPERTIES OF TYRE PYROLYSIS OIL

Tyre oil produced by the pyrolysis process was tested in the laboratory as per IS 1448 for determination of its physiochemical properties. The liquid obtained are dark brown coloured product. The carbon residue result for the tyre oil is 0.85%. A high carbon residue result may lead to coking of fuel injector nozzles in diesel engine.

The kinematic viscosity of the tyre oil is 6.3 cSt which is slightly higher than that of the diesel. Viscosity affects injector lubrication and fuel atomization. Fuels with low viscosity may not provide sufficient lubrication for the precision fit of fuel injection pumps or injector plunger resulting in leakage or increased wear. Fuel atomization is also affected by fuel viscosity. Fuel with high viscosity tends to form larger droplets on injection which can cause poor combustion and increased exhaust smoke and emissions. The flash point of a liquid fuel is the temperature at which the oil begins to evolve vapours in sufficient quantity to form a flammable mixture with air. The flash point of the tyre derived oil is 34°C. The flash point is lower than that of the diesel.

The low flash point of the tyre oil was not surprising since the oil was a mixture of components having a wide distillation range. The carbon and hydrogen contents of the tyre oil are comparable with that of diesel. Sulphur content was found less than that of the diesel. Nitrogen content is found similar to that of diesel, higher nitrogen content of the fuel may contribute to the formation of $NO_{X.}$ The Pour point is the temperature at which fuel thickness and will not pour and the value of pour point for the tyre oil is 6°C. The calorific value of the tyre oil is 44.3MJ/kg. The calorific value is high and comparable with that of a diesel.

Table 1 : Comparison of properties of diesel and TPO

Property	Diesel	Crude TPO	DPTO
Density in Kg/m^3	830	925	870
Kinematic cSt	4.1	8.2	6.3
Calorific Value	44.8	42.5	44.3
Flash Point in ^{0}C	50	42	34
Fire Point in ^{0}C	56	49	46

IV. EXPERIMENTAL SET UP

The experiments were carried out at a constant speed. The experiments were carried out using blends of DTPO with diesel and the blends were prepared using 1000ml measuring jar.

Schematic diagram of the engine test rig is shown in Fig.1. The engine test is conducted on four stroke single cylinder direct injection water cooled compression ignition engine connected to eddy current dynamometer loading. The engine is operated at a constant speed of 1500 rev/min. The engine has a compression ratio of 16.5 : 1 and a normal speed of 1500 rpm controlled by the governor. An injection pressure of 200 bar is used for the best performance as specified by the manufacturer. The engine is first run with the diesel at the loading conditions of 2, 4, 6 and 8 kgs. Between two load trails the engine is allowed to become stable by running it for 20 minutes before taking the readings. At each loading condition performance parameters namely speed, exhaust gas temperature, brake power, peak pressure are measured under steady state conditions. The experiments are repeated for various combinations of DTPO blends. With the above experimental results the parameters such as total fuel consumption, brake specific fuel consumption, brake mean effective pressure, brake specific energy consumption and brake thermal efficiency are determined.

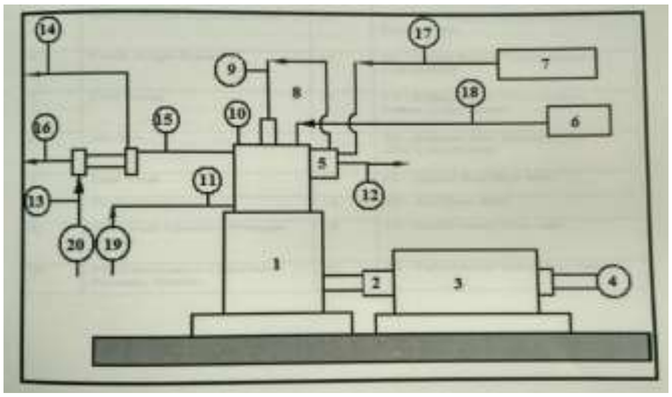

Fig.1. schematic diagram of the experimental setup

Table 2: Components of the CI Engine

Sl.no	Components	Sl.no	Components
1	Engine	11	Jacket water Inlet Temperature
2	Load cell	12	Jacket water outlet temperature
3	Eddy current Dynamometer	13	Inlet water temperature at calorimeter
4	Crank angle Encoder	14	Outlet water temperature at calorimeter
5	Fuel pump	15	Exhaust gas temperature before calorimeter
6	Air Box	16	Exhaust gas temperature after calorimeter
7	Fuel tank	17	Liquid fuel flow rate
8	Fuel Injector	18	Air flow rate
9	Fuel injection Pressure sensor	19	Jacket water flow rate
10	Combustion chamber Pressure sensor	20	Calorimeter water flow rate

Table 3: Specification of the CI Engine

Engine parameters	**Specification**
Engine	Four stroke single cylinder
Make	TV1 Kirloskar
Number of cylinders	Single Cylinder
BHP	5 HP
RPM	1500
Fuel	Diesel and blends of TPO
Bore	80 mm
Stroke length	110 mm
Compression ratio	16.5 : 1
Starting	Cranking
Working cycle	Four stroke
Method of cooling	Water cooled
Method of ignition	Compression ignition
Dynamometer	Rope Break Dynamometer

V. RESULTS AND DISCUSSION

Brake thermal efficiency (BTE)

The variation of brake thermal efficiency for different engine loads and constant speed are as shown in the Fig.2.

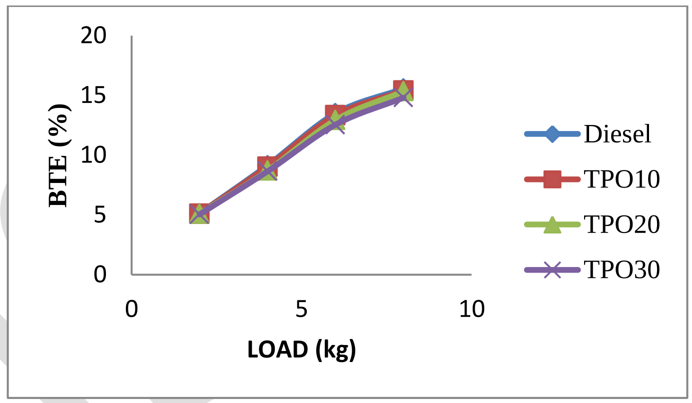

Fig.2 Variation of the Brake Thermal Efficiency versus Load

The Fig.2 shows the variation of the brake thermal efficiency versus load for compression ratio of 16.5 for different blends of distilled tyre pyrolysis oil respectively. It is observed that the thermal efficiency is gradually increased with increase in load. The thermal efficiencies of the blends decrease with the increase in TPO of the blend. This may be due to the lower heating value of DTPO.

Brake specific Fuel consumption (BSFC)

The variation of brake specific fuel consumption for different engine load conditions and for compression ratio 16.5 is as shown in the Fig.3

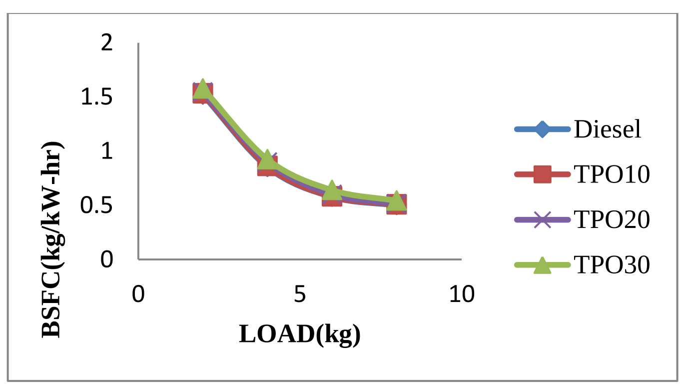

Fig.3 Variation of Brake Specific Fuel Consumption versus Load

Fig.3 shows the variation of brake specific fuel consumption for different blends of distilled tyre pyrolysis oil respectively. It is observed that the BSFC is gradually decrease with increases in the load condition. At the same time it also shows that BSFC increases with the increase in the concentration of DTPO in diesel. This behaviour is obvious since the engine will consume more fuel with DTPO diesel blends than diesel, to gain the same power output owing to the lower calorific value of DTPO.

VI. CONCLUSION

Pyrolysis of scrap tyres produces oil that can be used as a liquid fuels for industrial furnaces, foundaries and boilers in power plants due to their higher calorific value, low ash, residual carbon and sulphur content. However higher density, kinematic viscosity and lower centane number of tyre oil suggests that behaviour of tyre oil in IC engines can be studied through blending tyre oil with diesel in various proportions keeping the blend quality by controlling density and viscosity of the blend with in permissible limit for performance test. Further improvement in fuel quality in terms of desulphurisation, reduction in viscosity and aromatic contents and increase in centane number is required by proper distillation of tyre oil and use of proper centane enhancer is necessary if tyre oil is to be used as a fuel in Internal Combustion engine. BSFC is gradually decreased with increases in load. TPO10 and TPO20 blends can be directly used in diesel engines without any engine modifications. The brake thermal efficiency of TPO blended diesel is less than that of diesel. The specific fuel consumption of blends is higher than that of the diesel. To run higher blends of the TPO certain engine modifications are required.

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